Project Stage	General Topic	Specific Metric(s)	Analysis Already Agreed To By USAF?
Pre-Baseline			
	Monitoring Well Installations		
		Continuous logging	Y
		PID readings	Y
		LNAPL Dye Test; VOC and TPH if Dye Test is Positive	Y
		VOCs	Y
		TPH (DRO, GRO)	Y
Baseline Data			

Timing of Analyses	Frequency of Analyses	Location of Analyses
Before baseline geochemistry, field data, and microbial analyses performed	(Once - is an installation)	(Location of Installations)
	Once	CZ
	Once	UWBZ
	Once	LSZ
during well installation		Following Table 5.1
during well installation		Following Table 5.1
during well installation		Following Table 5.1
		Following Table 5.1
		Following Table 5.1

Purpose
These are additional wells to provide accurate monitoring of EBR
These MWs are needed to ensure that there are sufficient data to evaluate the effectiveness of EBR. The extraction wells can be used, but must be considered in separate groups and are not sufficient for this evaluation.
To determine if benzene is slower to degrade than other aromatics (or faster, or average)
To provide one singular, synoptic round of data prior to inception of EBR

Additional Comments
MWs are needed in suitable locations to monitor the effectiveness of EBR. Otherwise, data evaluation will be much less meaningful. Accurate delineation of concentrations in downgradient portions of the site should also be emphasized relative to off-site migration potential, sulfate utilization, etc. To the degree possible, wells should also be located so that aquifer heterogeneities (low-permeability zones) can be monitored and accurate spatial averages for parameter values can be computed. New MWs must have time to equilibrate after installation and development before baseline field data, geochemistry, and microbial analyses are performed.
7 treatment "ovals" proposed, but only 3 ovals have monitoring wells that are in reasonable locations. Monitoring wells should be installed in locations between the injection and extraction wells to evaluate sulfate distribution and EBR progress (5/ll/17 BCT slides, slide 25)
5 initial treatment "ovals" proposed; however, only one of the first 5 "ovals" where EBR is proposed for initial implementation has a monitoring well (ST012-UWBZ24). This well is not located in an optimal location for monitoring the effectiveness of treatment (i.e., it Is not located on the path between the injection and extraction wells). Since these ovals are proposed for the initial injections, at least one monitoring well should be installed in each oval treatment area so that the injections and EBR progress can be monitored. There are 5 additional treatment "ovals," but there are no monitoring wells in these ovals; monitoring wells should be installed (5/11/17 BCT slides, slide 26)
15 treatment "ovals" proposed, but only 2 have monitoring wells in suitable locations. 3 additional "ovals" have monitoring wells located beyond the extraction well. Depending on how the extraction wells are pumped, sulfate may never reach these monitoring wells. Monitoring wells should be installed in locations that are suitable to monitor injections and EBR progress. The wells located beyond the extraction wells should also be monitored to evaluate sulfate distribution (5/11/17 BCT slides, slide 27)
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016)
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016)
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016)
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016)
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016)
These data, collectively, will help establish baseline criteria against which project progress and goals can be compared and monitored.

Hydrogeologic Data

Groundwater gauge data (depth to water, depth to product, product thickness)	
Perform Slug Tests	

Mapping Contaminant Locations and Concentrations

Continue to locate and map LNAPL presence and depth	Y
Monitor benzene content and concentration in LNAPL, where LNAPL is found	Y
Continue to locate and map dissolved-phase benzene presence and concentration	Y
Continue to locate and map dissolved-phase VOC presence and concentration	
Calculate total LNAPL mass present at start of EBR	Y
Determine the content of COCs in the LNAPL at the start of EBR	
Locate and map sulfate concentrations	Y

Modeling

After SEE but before EBR injections or amendments	Once as baseline	New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area
		All New Wells and Existing Wells that have not been tested
After SEE but before EBR injections or amendments	Once as baseline	New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area
	Monthly	Perimeter wells
		New and existing MWs with recoverable LNAPL
After SEE but before EBR injections or amendments	Once as baseline	Targeted treatment area and downgradient portions of the site

For use in modeling
Hydraulic Conductivity Measurement; for use in modeling
Refer notes in "modeling" section of this table.
Comparison of NAPL compositions before/during EBR to assess reductions in COC content
When compared to this baseline data, this information will help monitor for sulfate migration outside of the COC areas and facilitate comparison of EBR modeling results with field data

Data should be acquired for all three zones, including CZ
Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater ~~to produce gw~~ flow directions
Data should be acquired for all three zones, including CZ
See modeling comments by Bo Stewart, 5/17
Need to ensure good knowledge of locations where EBR treatments/amendments are being conducted, as well as downgradient
Need to develop a good baseline of initial NAPL content at locations where EBR treatments/amendments are being conducted, as well as downgradient
Report (graph) dissolved-phase trends over time, in addition to LNAPL trends for perimeter wells
ADEQ transmitted extensive comments on the most recent AF mass and composition estimates of remaining NAPL on May 16.
The existing characterization of NAPL composition is dated and displays a large deviation in a relatively small set of analyses. The most recent samples were collected from a NAPL holding tank. This NAPL was the combined recovery from the CZ, UWBZ and LSZ with unknown fractions from each. To allow a meaningful comparison of NAPL compositions before/during EBR to assess reductions in COC content, a large set of NAPL samples should be collected and analyzed separately from each zone and across each zone.

Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil	
Provide details of EBR modeling to calculate time estimates for remediation	
Provide proof of concept supporting the sulfate reduction for EBR	
Provide details used to determine the optimal sulfate injection strategy.	

GW Geochemistry

Temperature	Y
pH	Y
ORP value	Y
Dissolved Oxygen	Y
Nitrate	Y
Phosphorus	
Ferrous Iron	
Total Iron	
Sulfate	Y
Hydrogen Sulfide	
Methane	
Alkalinity	
TPH (DRO, GRO)	Y
VOCs	Y
Arsenic	Y

After SEE but before EBR injections or amendments	Once as baseline	New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area

The EBR modeling efforts conducted by the AF, while perhaps useful from an operational standpoint, do not provide a sufficiently extensive and detailed evaluation of important factors determining the efficacy and rate of COC biodegradation, and depletion of COCs from the LNAPL source materials. For instance, the AF EBR modeling efforts assume instantaneous mass transfer of COCs from the LNAPL to groundwater, which likely significantly over-estimates actual rates of transfer of COCs, therefore leading to over-estimates of rates of COC depletion from the LNAPL. In addition, the AF EBR modeling efforts assumed site-wide uniformity of critical parameters (such as porosity) [< They actually did use several different permeability zones in their model; I think we can leave this sentence out]. AF did not provide sensitivity analyses for evaluating the effect of these assumptions on remedial efficacy and timeframe scenarios. Therefore, the Regulatory Team has performed a detailed and extensive analysis and modeling effort to better capture the variability of physical, chemical and biological conditions across the site, and to show the range and likelihood of possible remedial efficacy and timeframe outcomes of EBR and MNA [ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls].

Modeling to date by the AF has not been sufficiently documented to allow an independent check on the results. The Regulatory Agencies technical team has sent a list of these deficiencies to AF.

In particular, very little field data exists for the CZ and the UWBZ. The AF has not performed the EBR pilot test in the UWBZ that was agreed to in the ST012 Work Plan.

Reported on AF flowchart as Eh

AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored

AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored

Indigenous Microbial Population

Total size	
Major groups within population, and their proportion of total	
Total size of sulfate-reducing bacteria population	Y
Total size of benzene-degrading bacteria population	
In-situ benzene degradation rate	
Amount of benzene converted to biomass during stable isotope study	Y
Amount of benzene converted to carbon dioxide during stable isotope study	Y
The overall health of the indigenous microbial population, as determined via PLFA analyses	
The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion	

Assessments During EBR

Hydrogeologic Data

Groundwater gauge data (depth to water, depth to product, product thickness)	
Biofouling	Y

Mapping Contaminant Locations and Concentrations

After SEE but before EBR injections or amendments	Once to establish baseline	Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient. All three zones should be monitored. The same wells should be monitored pre-EBR, during EBR, and post-EBR.
		New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area
	quarterly	
During EBR		All new and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area

These analyses will quantify the size, makeup, and health of the indigenous microbial community.

These assessments will be used to monitor the progress of EBR, and to determine if changes to the EBR strategy need to be made. These will also help monitor progress of EBR.

All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population.

These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL.

qPCR performed in addition to the stable-isotope study. AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart.

Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater ~~to produce gw~~ flow directions

See AF Decision Tree

Locate and map LNAPL presence and depth - monitoring wells	y
Locate and map dissolved-phase benzene presence and concentration	y
Locate and map dissolved-phase VOC presence and concentration	y
Calculate total LNAPL mass	
Determine the content of COCs in the LNAPL	
Locate and map sulfate concentrations in the targeted treatment area as well as downgradient	Y

Modeling

Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil	
Provide details of EBR modeling to calculate time estimates for remediation	
Provide proof of concept supporting the sulfate reduction for EBR	
Provide details used to determine the optimal sulfate injection strategy.	

copy comment from pre EBR section ????

GW Geochemistry

Temperature	Y
pH	Y
ORP value	Y
Dissolved Oxygen	Y

	Timing of sampling and analysis to follow schedule outlined in Table 4.1 of referenced document; mapping performed once per month	
	Quarterly	
	Quarterly	MWs with recoverable NAPL located in the area to be impacted by injections/ amendments
During EBR	At least annually	
During EBR	Monthly for the first quarter of EBR, followed by quarterly	New and existing MWs

Comparison of NAPL compositions before/during EBR to assess reductions in COC content
Demonstrate achievement of remediation goals based on observed benzene concentration reductions in LNAPL and groundwater. Modeling and analyses of field data should also incorporate geochemical (e.g., sulfate) and microbial data (e.g., biomass) parameters that support hydrocarbon mineralization by biodegradation mechanisms (separate from dilution or sorption mechanisms). Modeling needs to evaluate rate-limited dissolution of LNAPL constituents so that the extent to which benzene and other hydrocarbon concentration reductions in groundwater are due to slow NAPL/aqueous-phase mass transfer (refer to example calculations in "Figures" tab). Sensitivity analyses should also be performed to rigorously document the variability of remediation timeframes as a function of EBR parameters.

Need to ensure good knowledge of locations where EBR treatments/amendments are being conducted, as well as downgradient. Timing schedule found in: Final Field Variance Memorandum #5 – Extraction and Treatment System Construction, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona; 01 Dec 2016
Measurements of NAPL content, specifically benzene mole fraction, are a primary parameter for assessing EBR performance. See the "Figures" tab for example plots of benzene mole fraction. Refer to other comments in "modeling" sections of this table.
When compared to this baseline data, this information will help monitor sulfate migration outside of the COC areas
The EBR modeling efforts conducted by the AF, while perhaps useful from an operational standpoint, do not provide a sufficiently extensive and detailed evaluation of important factors determining the efficacy and rate of COC biodegradation, and depletion of COCs from the LNAPL source materials. For instance, the AF EBR modeling efforts assume instantaneous mass transfer of COCs from the LNAPL to groundwater, which likely significantly over-estimates actual rates of transfer of COCs, therefore leading to over-estimates of rates of COC depletion from the LNAPL. In addition, the AF EBR modeling efforts assumed site-wide uniformity of critical parameters (such as porosity) [< They actually did use several different permeability zones in their model; I think we can leave this sentence out]. AF did not provide sensitivity analyses for evaluating the effect of these assumptions on remedial efficacy and timeframe scenarios. Therefore, the Regulatory Team has performed a detailed and extensive analysis and modeling effort to better capture the variability of physical, chemical and biological conditions across the site, and to show the range and likelihood of possible remedial efficacy and timeframe outcomes of EBR and MNA [ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls].
Ongoing updates as field data become available. Modeling to date by the AF has not been sufficiently documented to allow an independent check on the results. The Regulatory Agencies technical team has sent a list of these deficiencies to AF.
Ongoing updates as field data become available
These analyses will provide an indirect method of monitoring the indigenous microbial community.
Reported on AF flowchart as Eh

Nitrate	Y
Phosphorus	
Ferrous Iron	
Total Iron	
Sulfate	Y
Hydrogen Sulfide	
Methane	
Alkalinity	
TPH (DRO, GRO)	Y
VOCs	Y
Arsenic	Y

TEA Injection Fluid

ICP Metals	Y
Details of injection material composition	
Sulfate	Y
Location of each injection/amendment	
Concentration of sulfate at each injection/ amendment location	
Anticipated zone of influence for each injection/ amendment	

Indigenous Microbial Population

Total size	
Major groups within population, and their proportion of total	
Total size of sulfate-reducing bacteria population	Y

During EBR, for every injection/ amendment event and location		
	Monthly, per Table 5.1 Need to check each batch	
During EBR, 6-9 months post-injection (per Decision Matrix)	At least once during EBR, 4-6 weeks after initial sulfate injection. May need to be repeated if geochem data suggests a problem.	Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient. All three zones should be monitored. The same wells should be monitored pre-EBR, during EBR, and post-EBR.

To help monitor key microbial nutrient availability
Will help determine preferred TEA for indigenous microbes
Will help determine preferred TEA for indigenous microbes
To monitor if periodic sulfate injections or recirculation are necessary to sustain degradation rates
To monitor if hydrogen sulfide concentrations inhibit degradation or will subsurface conditions mitigate their buildup?
To record makeup and concentration of injection fluid
Will the injected sulfate become well distributed with respect to NAPL accumulations?
These analyses will quantify the size, makeup, and health of the indigenous microbial community. If there are indications that the microbial population is struggling during EBR, the analyses should be repeated to determine if alternate strategies are needed
May also help determine lag time for SRBs to acclimate to elevated sulfate concentrations and determine if highly concentrated injections of sulfate will be inhibitive to bacterial activity

AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored
AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016);   This data will provide a record of exactly what was injected, where, and at what concentration. This, when compared with the response by the contaminants and other geochemical and biological data, will help determine if any changes need to be made to amendment variables such as frequency, concentration, etc.
Any metals over MCL would prevent ability to inject
This may be proprietary; however, an effort to obtain this information should be made
Need to check the TEA fluid before injection ~~fluid before goes into ground~~ to ensure that the concentration is as expected , was mixed and diluted correctly, etc.
All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population. These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL.
Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016).   AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart.   qPCR performed in addition to the stable-isotope study.

Total size of benzene-degrading bacteria population	
In-situ benzene degradation rate	
Amount of benzene converted to biomass during stable isotope study	Y
Amount of benzene converted to carbon dioxide during stable isotope study	Y
The overall health of the indigenous microbial population, as determined via PLFA analyses	
The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion	

Post-EBR Data

Hydrogeologic Data

Groundwater gauge data (depth to water, depth to product, product thickness)	
Biofouling	Y

Mapping Contaminant Locations and Concentrations

Locate and map LNAPL presence and depth	

Post-EBR		Each MW used for injections, amendments, or any analyses
	Minimum of semi-annual	
	once	
Post-EBR	Quarterly, then frequency amended per modeling and EPA guidance on MNA	Each MW used for injections, amendments, or any analyses

This data will be compared against baseline data, and data taken during EBR, to determine the success of the project as well as to identify necessary future actions. This data will also become the baseline information used at the start of MNA
To ensure no biofouling after EBR

EBR remedial goals include:

1) Depletion of COC concentrations (mole fractions) in on- and off-site LNAPL to the degree that the COC-depleted LNAPL cannot transfer COCs to groundwater above MCLs [< Is there "off-site" LNAPL ?]

2) Reduction of aqueous-phase COC concentrations in on- and off-site groundwater and soil to the degree that MNA could be expected (based on Regulatory Agency modeling) to reduce COCs in on- and off-site groundwater below MCLs within the ROD remedial timeframe. [< I added "soil" because most of the aqueous-phase SVOC mass, and almost half of the aqueous-phase benzene mass, is sorbed to the soil matrix; this allows us to evaluate rate-limited aqueous-phase diffusion of mass out of low-permeability zones]

Specific numerical metrics, milestones, and timelines (i.e., specific concentrations of COCs in LNAPL and groundwater on- and off-site, along with associated geochemical and microbiological data, at specific times after initial implementation of EBR, and of MNA) will be developed based on Regulatory Agency modeling efforts to guide remedial activities, evaluate success of the remedial approaches, and trigger contingency remedies if necessary.

Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater ~~to produce gw~~ flow directions

Pope, Daniel F., Steven D. Acree, Herbert Levine, Stephen Mangion, Jeffrey van Ee, Kelly Hurt, Barbara Wilson, Performance Monitoring of MNA Remedies for VOCs in Ground Water EPA/600/R-04/027, National Risk Management Research Laboratory Office Of Research And Development U.S. Environmental Protection Agency, Ada OK, 2004

Locate and map dissolved-phase benzene presence and concentration, in excess of 5 ug/L	
Locate and map dissolved-phase VOC presence and concentration	
Calculate total LNAPL mass present	
Determine the content of COCs in the LNAPL	
Locate and map sulfate concentrations in the targeted treatment area as well as downgradient	Y

Modeling

Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil by MNA	
Provide details of post-EBR modeling to calculate time estimates for remediation	

GW Geochemistry

Temperature	Y
pH	Y
ORP value	Y
Dissolved Oxygen	Y
Nitrate	Y
Phosphorus	
Ferrous Iron	
Total Iron	
Sulfate	Y
Hydrogen Sulfide	

		MWs with recoverable NAPL located in the area to be impacted by injections/ amendments
Post-EBR	As needed	
Post-EBR	Quarterly, then frequency amended per modeling and EPA guidance on MNA	Each MW used for injections, amendments, or any analyses

Comparison of NAPL compositions before/during/after EBR to assess reductions in COC content
Demonstrate achievement of remediation goals based on observed benzene concentration reductions in LNAPL and groundwater. Modeling and analyses of field data should also incorporate geochemical (e.g., sulfate) and microbial data (e.g., biomass) parameters that support hydrocarbon mineralization by biodegradation mechanisms (separate from dilution or sorption mechanisms). Modeling needs to evaluate rate-limited dissolution of LNAPL constituents so that the extent to which benzene and other hydrocarbon concentration reductions in groundwater are due to slow NAPL/aqueous-phase mass transfer (refer to example calculations in "Figures" tab). Sensitivity analyses should also be performed to rigorously document the variability of remediation timeframes as a function of EBR parameters.

Update based on additional field data
Measurements of NAPL content, specifically benzene mole fraction, are a primary parameter for assessing EBR performance. See the "Figures" tab for example plots of benzene mole fraction. Refer to other comments in "modeling" sections of this table.
When compared to this baseline data, this information will help monitor sulfate migration outside of the COC areas
The EBR modeling efforts conducted by the AF, while perhaps useful from an operational standpoint, do not provide a sufficiently extensive and detailed evaluation of important factors determining the efficacy and rate of COC biodegradation, and depletion of COCs from the LNAPL source materials. For instance, the AF EBR modeling efforts assume instantaneous mass transfer of COCs from the LNAPL to groundwater, which likely significantly over-estimates actual rates of transfer of COCs, therefore leading to over-estimates of rates of COC depletion from the LNAPL. In addition, the AF EBR modeling efforts assumed site-wide uniformity of critical parameters (such as porosity) [< They actually did use several different permeability zones in their model; I think we can leave this sentence out]. AF did not provide sensitivity analyses for evaluating the effect of these assumptions on remedial efficacy and timeframe scenarios. Therefore, the Regulatory Team has performed a detailed and extensive analysis and modeling effort to better capture the variability of physical, chemical and biological conditions across the site, and to show the range and likelihood of possible remedial efficacy and timeframe outcomes of EBR and MNA [ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls].
Pope, Daniel F., Steven D. Acree, Herbert Levine, Stephen Mangion, Jeffrey van Ee, Kelly Hurt, Barbara Wilson, Performance Monitoring of MNA Remedies for VOCs in Ground Water EPA/600/R-04/027, National Risk Management Research Laboratory Office Of Research And Development U.S. Environmental Protection Agency, Ada OK, 2004
Reported on AF flowchart as Eh
AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored
AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored

Methane	
Alkalinity	
TPH (DRO, GRO)	Y
VOCs	Y
Arsenic	Y

Indigenous Microbial Population

Total size	
Major groups within population, and their proportion of total	
Total size of sulfate-reducing bacteria population	Y
Total size of benzene-degrading bacteria population	Y
In-situ benzene degradation rate	
Amount of benzene converted to biomass during stable isotope study	Y
Amount of benzene converted to carbon dioxide during stable isotope study	Y
The overall health of the indigenous microbial population, as determined via PLFA analyses	
The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion	

Post-EBR	Once, within 3 months of the last injection/ amendment	Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient. All three zones should be monitored. The same wells should be monitored pre-EBR, during EBR, and post-EBR.

These analyses will quantify the size, makeup, and health of the indigenous microbial community at the end of EBR, and will provide baseline data for MNA

All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population.

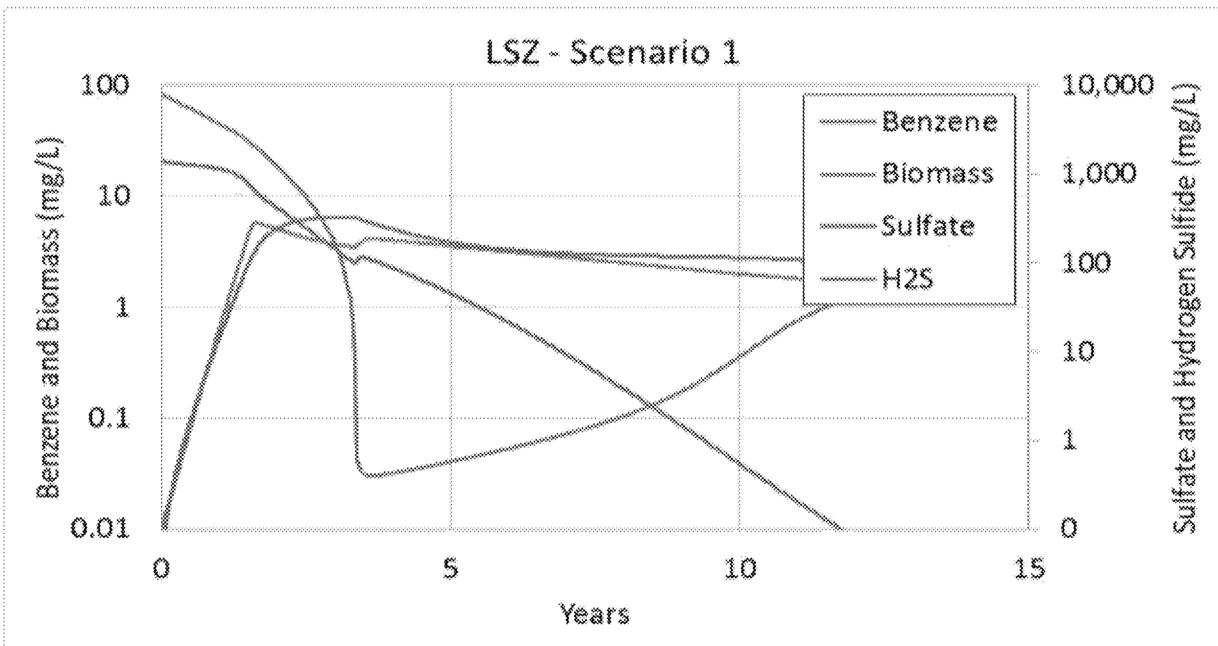
These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL. The use of the stable-isotope probes would be anticipated as a one-time event, unless groundwater data suggests a need to perform it again.

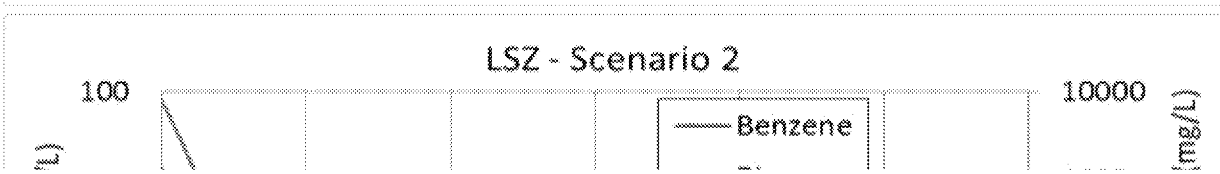
AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart. qPCR performed in addition to the stable-isotope study.

Example calculations based on scenarios described in "Time of Remediation Estimates, Enhanced Bioremediation at ST01
Calculation input is provided in Tables 8-10 of the TOR memorandum

Table 8. Parameters for Monod Kinetics

Parameter		UWBZ	LSZ	Reference
V_{Soil}	yd^3	122,556	38,500	Table 2
Q	gpm	4.4	3.5	Table 2
k_{NAPL}	1/day	0.05	0.05	Mobile et al. (2016)
C^{O2} (backgrnd)	mg/L	7.0	7.0	Table M.4.3.2.1
C^{NO3-} (backgrnd)	mg/L	8.0	8.0	Table M.4.3.2.1
C^{SO4-} (backgrnd)	mg/L	200	290	Table M.4.3.2.1
γ^{SO4-}	g/g	4	4	Table M.4.3.5.3
$V^{max}_{Benzene,SO_4^{2-}}$	1/day	0.000875	0.0175	Table M.4.3.5.1/2
$V^{max}_{Toluene,SO_4^{2-}}$	1/day	0.001125	0.0225	Table M.4.3.5.1/2
$V^{max}_{Ethylbenzene,SO_4^{2-}}$	1/day	0.000875	0.0175	Table M.4.3.5.1/2
$V^{max}_{Xylenes,SO_4^{2-}}$	1/day	0.001125	0.0225	Table M.4.3.5.1/2
$V^{max}_{Naphthalene,SO_4^{2-}}$	1/day	0.000125	0.0025	Table M.4.3.5.1/2
$V^{max}_{TMB,SO_4^{2-}}$	1/day	0.000125	0.00125	Table M.4.3.5.1/2
$V^{max}_{Other\ Aromatics,SO_4^{2}}$	1/day	0.000625	0.0125	Table M.4.3.5.1/2
$K_{SO_4^{2-}}$	mg/L	1	1	Table M.4.3.5.3
$K_I^{SO_4^{2-}}$	mg/L	5	5	Table M.4.3.5.3
Y	g/g	0.2	0.2	BEM (2007)
$M_{SRB,o}$ (initial)	mg/L	0.01	0.01	BEM (2007)
$\lambda^{d,bk}_{SRB}$	1/day	0.001 / 0.0	0.001 / 0.0	BEM (2007)





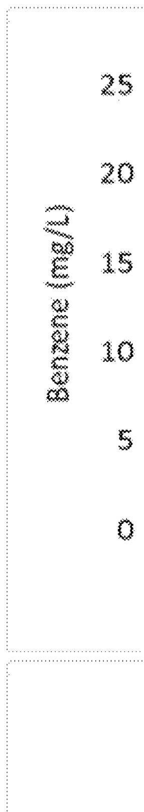
2" dated May 22, 2017

Table 9. Initial EBR-

Aquifer Zone		
UWBZ V = 122,556 cy	NAPL (gal)	
	Sulfate (kg) =	
	Sulfate (mg/L) =	
LSZ V = 38,500 cy	NAPL (gal)	
	Sulfate (kg) =	
	Sulfate (mg/L) =	

Table 10. TOR for NAPL Deple

Aquifer Zone	Ambient Flow gpm	Mass Transfer Coeff. day^{-1}	Calc Targe Vol Poros ye
UWBZ	4.4	0.0042	1
UWBZ	4.4	0.05	9
UWBZ	0.0*	0.05	1
LSZ	3.5	0.0042	5
LSZ	3.5	0.05	1
LSZ	0.0*	0.05	1

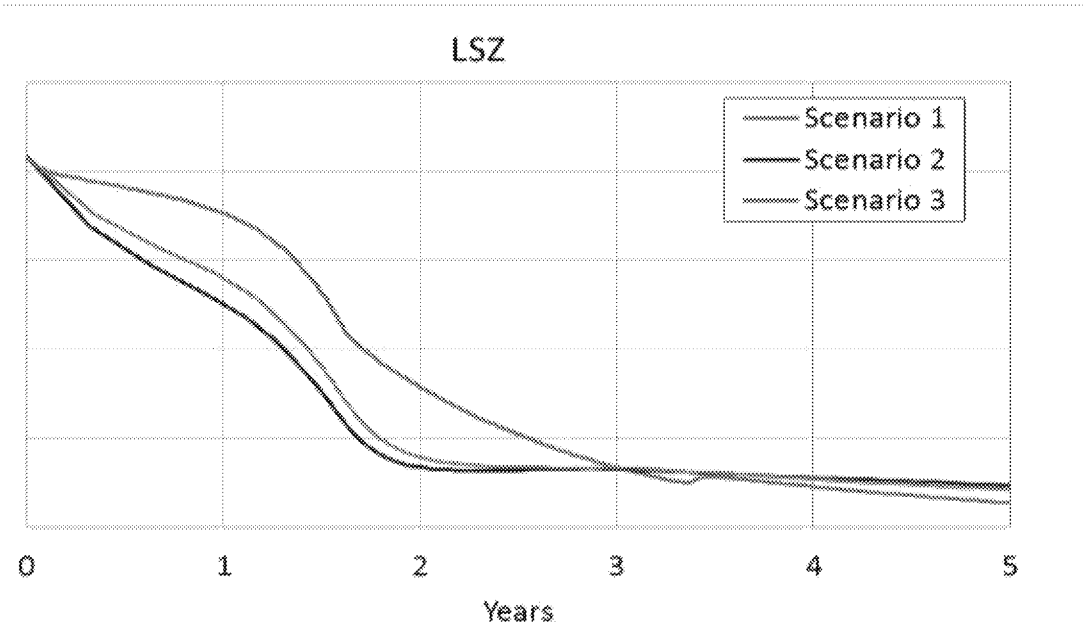


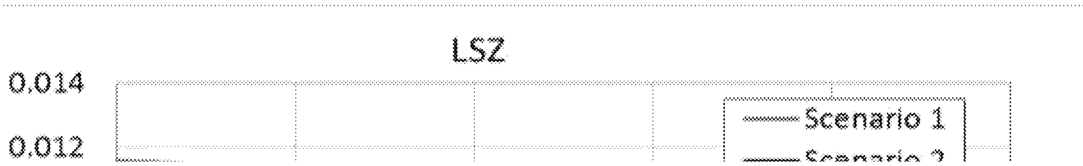
Targeted Sulfate Mass and Concentration

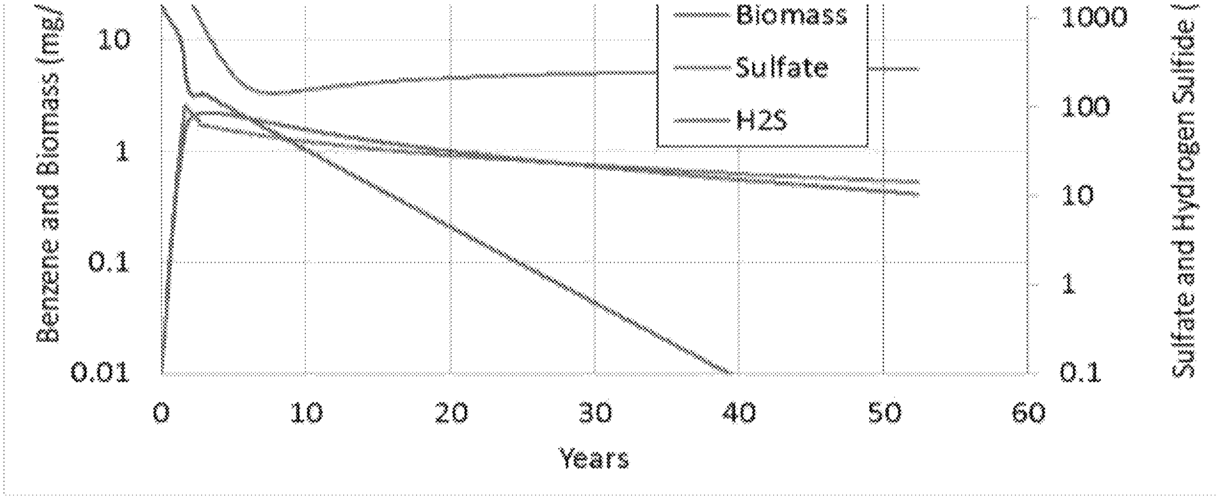
Calculated^ Target NAPL Volume Porosity=0.3 gal	Calculated^ Target NAPL Volume Porosity=0.4 gal	Literature* Target NAPL Volume Porosity=0.3 gal	Literature* Target NAPL Volume Porosity=0.4 gal
250,999	215,142	294,399	395,887
1,032,067	884,629	1,210,521	1,627,823
36,715	23,603	43,064	43,432
54,821	46,989	110,682	155,783
225,415	193,211	455,106	640,554
25,527	16,410	51,538	54,404

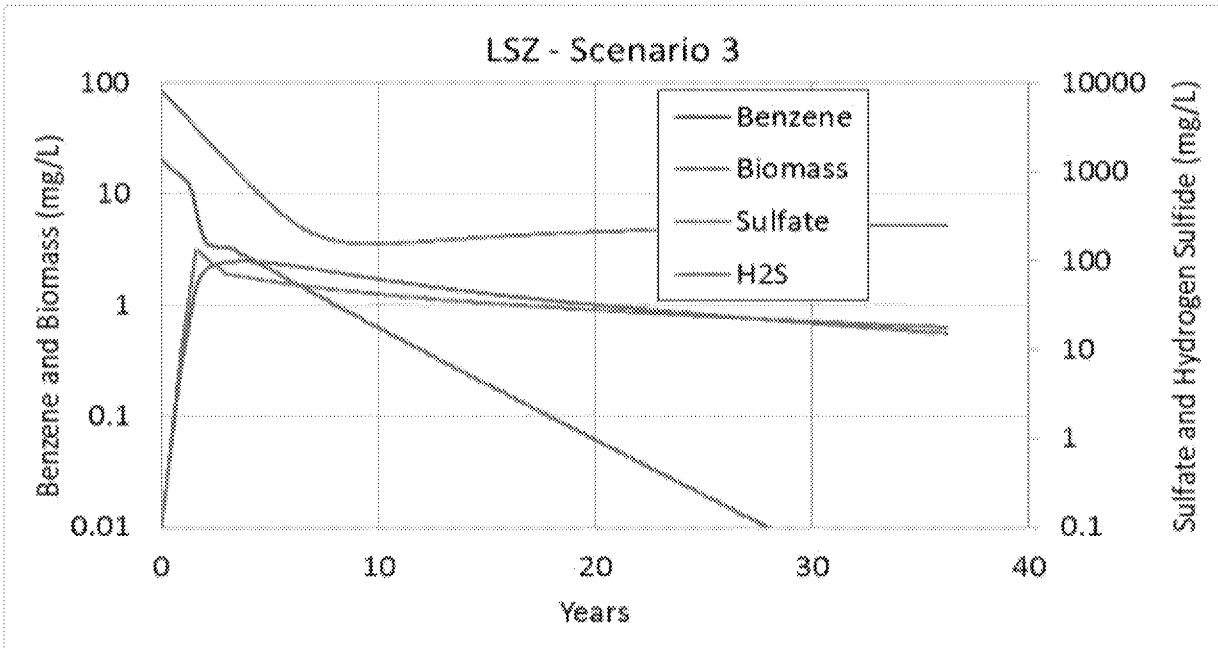
etion with Sulfate Reduction and Monod Kinetics

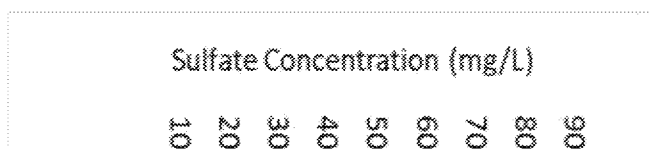
ulated et NAPL lume sity=0.3 ears	Calculated Target NAPL Volume Porosity=0.4 years	Literature Target NAPL Volume Porosity=0.3 years	Literature Target NAPL Volume Porosity=0.4 years	Notes
33	111	152	178	1
92	84	102	126	1
26	116	140	174	2
2.4 2	36.2 3	104	116	3
3.2 1	9.4	28.0	36.1	3
2.1	9.9	22.0	27.0	4

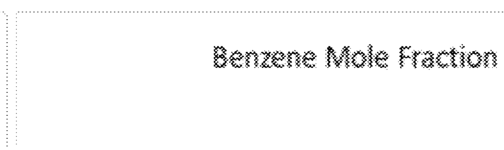


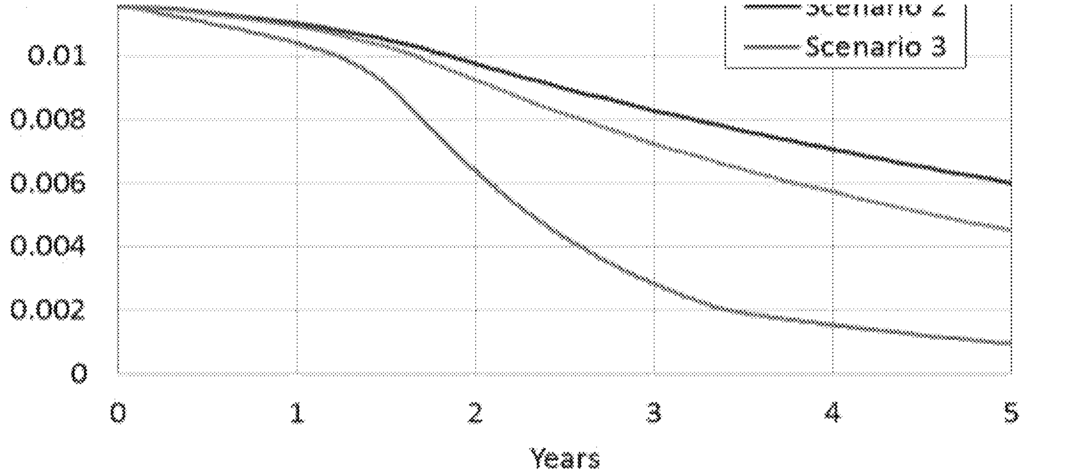


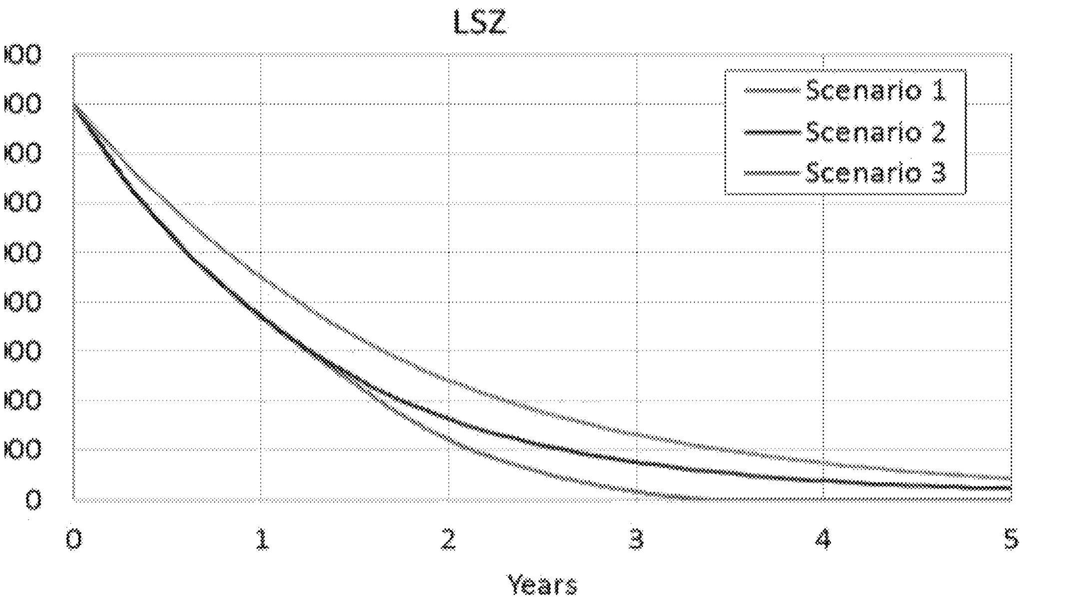

Biomass
Sulfate
H2S
10
1
0.1
0.01
1000
100
10
1
0.1
0
10
20
30
40
50
60
Years


LSZ - Scenario 3
Benzene
Biomass
Sulfate
H2S
Benzene and Biomass (mg/L)
Sulfate and Hydrogen Sulfide (mg/L)
100
10
1
0.1
0.01
10000
1000
100
10
1
0.1
0
10
20
30
40
Years


Sulfate Concentration (mg/L)
10
20
30
40
50
60
70
80
90


Benzene Mole Fraction


Scenario 2
Scenario 3
0.01
0.008
0.006
0.004
0.002
0
0
1
2
3
4
5
Years


LSZ
Scenario 1
Scenario 2
Scenario 3
0
0
1
2
3
4
5
Years